UK Energy Research Centre

UKERC ENERGY RESEARCH LANDSCAPE: Energy Storage

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1. Overview

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Characterisation of the Field

Energy storage can be divided into several broad categories, electrical, thermal and fuel. Electrical energy and thermal energy are usually generated from energy fuel on demand by scheduling generators, however energy storage may be used to increase efficiency. The increasing use of renewable energy sources, where availability may not coincide with demand, increases the need for electrical and thermal storage.

The scope of this Landscape is the storage of electricity, where the storage input and output are electrical power. This Landscape does not include the storage of thermal energy for end use; the storage of fossil fuels including gas, coal and oil; or the storage of other commodities used in electrical power generation such as uranium. Carbon Capture and Storage (CCS) is covered in the UKERC CO_2 Capture and Storage Landscape. Hydrogen storage is included where this is part of an electrical energy storage and regeneration system such as Power-to-Gas, while hydrogen storage generally is described in the UKERC Hydrogen Landscape.

Technologies used in electrical energy storage are covered, within the broad categories of chemical, mechanical, electrical and thermal technologies.

Electrical energy storage is an enabling technology at various scales, with application to a) the management of intermittency and efficiency in large scale power generation; b) transportation using low-emission electric vehicles (EVs); and c) portable electronics.

Interest is increasing generally in grid-scale electrical energy storage technology and applications. Investigations and reports have been completed in the UK and Europe, for example:

- The Energy Research Partnership published a report describing how energy storage could help meet the challenges that the UK's energy system will face in the transition to low-carbon over the next twenty years[1].
- The Carbon Trust commissioned a study to address some of the key questions in relation to the future role of electricity storage in the UK[2].
- The Low Carbon Innovation Co-ordination Group produced a Technology Innovation needs Assessment (TINA) for electricity networks and storage[3].
- The European Commission published a working paper on the future role and challenges of energy storage[4], and in 2020 published a Study on energy storage – Contribution to the security of the electricity supply in Europe[5]
- UK researchers produced a comprehensive study of the technologies and research and development needs in grid scale energy storage[6].
- The Renewable Energy Association (REA) published an overview of energy storage technologies and a list of installed energy storage systems in the UK[7].

The UK Government's Clean Growth Strategy (updated April 2018) plans to cut greenhouse gas emissions by upgrading our energy system, and announced an investment of £265m in smart systems to reduce the cost of electricity storage. In response, Ofgem produced a plan to upgrade our energy system and enable the transition to low carbon. Storage is seen to be an important part of a flexible energy system, and the plan includes discussion of actions to remove barriers to implementing effective storage and smart systems[8].

The Industrial Strategy Challenge Fund (ISCF), announced in the 2018 Budget, is part of the UK Government's Industrial Strategy, a long-term

plan to raise productivity and earning power in the UK. The fund is a core pillar in the Government's commitment to increase funding in research and development by £4.7 billion over 4 years to strengthen UK science and business, and will invest in the world-leading research base and highly-innovative businesses to address the biggest industrial and societal challenges today. The ISCF Faraday Battery Challenge is one of the 15 Challenges funded, and will invest up to £246m to develop batteries that are cost-effective, high-quality, durable, safe, low-weight and recyclable, with a focus on the next generation of batteries for electrical vehicles and other applications. The ISCF and the Faraday Battery Challenge include funding for basic research, applied research, and demonstration activity, and are described where appropriate in Section 3, Section 4, and Section 5.

The All Party Parliamentary Group (APPG) on Energy Storage, considered the opportunity for battery storage in the UK, not only to provide energy security, but also to provide export potential[9].

The Engineering and Physical Sciences Research Council (EPSRC) has identified storage as a priority area, in order to maintain and further develop energy storage research in the UK. Funding in the UK for basic and applied research and development of storage systems has increased dramatically in recent years.

In January 2009 EPRSC's energy storage grant portfolio in the Energy Programme included 15 grants with total value £8m; while in 2013 EPSRC support for the energy storage topic included 23 grants, with total grant value £37m. In 2019 the EPSRC Energy Storage Research Area has 65 relevant grants with proportional value £106m, equivalent to 2.22% of the total EPSRC portfolio.

Research Challenges

A particular uncertainty and area for research and development is the cost and lifetime of candidate storage technologies when applied to real duty cycles within electricity networks.

The UK is well established as a centre for battery development, with the main focus on lithium batteries, an important technology for mobile and stationary applications alike. Cryogenic (liquid-air) energy storage is also a UK strength.

The main research and development challenges are to reduce cost, and improve storage performance particularly in terms of energy density and round-trip efficiency, and lifetime during charge and discharge cycling. Research needs for storage technologies have been comprehensively described in research reports[4,6], and generally include research into new materials and manufacturing methods.

References

1 Energy Research Partnership: The Future Role of Energy Storage in the UK, June 2011
2 Report for the Carbon Trust: Strategic Assessment of the Role and Value of Energy Storage Systems in the UK Low Carbon Energy Future, Imperial College, June 2012
3 Low Carbon Innovation Co-ordination Group: Electricity Networks and Storage Technology Innovation Needs Assessment, August 2012
4 European Commission DG for Energy: The future role and challenges of Energy Storage, January 2013
5 European Commission DG for Energy: Study on energy storage – Contribution to the security of the electricity supply in Europe, March 2020
6 Brandon et al., UK Research Needs in Grid Scale Energy Storage Technologies, April 2016
7 Renewable Energy Association (REA): Energy Storage in the UK, An Overview, 2nd Edition Autumn 2016
8 Ofgem, Upgrading our Energy System, July 2017
9 All Party Parliamentary Group (APPG) on Energy Storage, and Renewable Energy Association (REA): Batteries, Exports, and Energy Security, December 2017

2. Capabilities Assessment

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Research and development of energy storage technologies has a long history in the UK.

UK Universities have particular strengths in materials for clean energy applications and in catalysis. Many Universities are active in battery research and development, as described in Section 3. There is also significant commercial R&D activity and expertise in all storage technologies and particularly in materials for electrochemical batteries. Some of the emerging capabilities in the UK are described in this section.

Battery storage systems in the electricity distribution network are already at the commercial deployment stage in the UK. There are numerous start-up companies, for example, Zenobe Energy deployed over 70MW at nine sites as of 2019. Moixa is a leading smart battery company, deploying residential batteries and solar systems since 2010, and offers integrated hardware and software for renewable energy management. RNA Energy has already over 200MW of operating renewable energy assets in the UK and in 2019 formed a joint venture with Nippon to construct two 50MW behind-the-meter storage projects in the UK. Pivot Power is developing the world's largest transmission-connected battery storage and electric vehicle charging network, and is the lead participant in the Energy Superhub Oxford project.

Statistics on energy storage projects published by RenewableUK in December 2019 shows that energy storage power capability is increasing rapidly in the UK, with 0.742GW of operational battery storage capacity and over 10GW of planning applications. Pumped storage is also increasing from 2.833GW operational, and 1.796GW planned. While lithium batteries make up the majority of planned projects, the next phase of growth will include a range of new technologies. Companies ranging from Siemens to Highview Power are developing hydrogen, ammonia, and compressed air and liquid air storage technologies, with 0.600GW in development.

Meanwhile research continues in many storage technologies.

Lithium batteries

Significant advances in lithium-ion (Li-ion) battery technology have been historically made in the UK. AEA Harwell, working with Dowty Battery Co. in the 1990's, developed solid-state lithium batteries with polymer electrolyte and composite cathode. There are established academic centres, and technology development and commercial exploitation continues with several companies in the field.

Johnson Matthey Battery Systems (formerly Axeon UK) is one of Europe's largest lithium-ion battery systems suppliers, processing over 70 million cells a year, and supplying volume production of batteries for global markets. In Poland, Johnson Matthey designs and manufactures high performance battery packs for the professional cordless power tools and electric bike markets. The UK-based automotive battery systems business was acquired by Cummins in January 2018.

Nexeon (Abingdon) is a world leader in engineered silicon materials for battery applications. Nexeon's technology uses silicon in several forms to enhance or replace the traditional graphite anode in a lithium ion battery. The technology has the potential to improve cycle life and significantly increase the capacity of Li-ion batteries used in electric vehicles and a wide range of consumer electronics.

OXIS Energy (Abingdon) has been at the forefront of building next generation batteries since 2004. The company has developed its unique Lithium-sulphur (Li-S) technology around a sulphur based cathode, Lithium metal anode, and a safe and highly stable electrolyte.

Flow batteries

There are two main classes of flow batteries – the redox (reduction-oxidation) flow battery, and the hybrid flow battery where the electrodes are part of the chemical reaction (as in a battery).

The UK has been active in flow battery development. In the 1990's Regenesys (UK) developed polysulphide bromide technology to an advanced stage, and two demonstration plants of 15MW and 120MWh capacity were constructed but not commissioned. The technology rights were acquired by VRB Power Systems (Vancouver) in 2004 to complement its own technologies (vanadium), providing products for very large utility-scale applications from 10–100MW, with eight to ten hours' storage time. VRB ceased trading in 2008 and after several changes of ownership the technology is now marketed by VRB Energy.

redT Energy PLC (Renewable Energy Dynamics Technology) developed three generations of vanadium redox battery in the UK since 2016. In 2019, redT flow batteries achieved pre-qualification status from National Grid to provide Dynamic Firm Frequency Response (dFFR) services to the UK electricity transmission grid. The company is supplying a 2.5 MW / 5 MWh vanadium redox flow cell as part of a 60MW flow/hybrid energy storage system to the Energy SuperHub Oxford project. In 2020 redT Energy and Avalon Battery merged to form Invinity Energy Systems, now a worldwide leader in vanadium flow batteries and a competitor to lithium-ion technology.

Research on zinc-cerium flow batteries continues at the Universities of Strathclyde and Southampton. The University of Southampton is also researching the soluble lead redox flow battery (SLFB).

Flywheels

Urenco Power Technologies (UPT) developed a 2kWh capacity flywheel with a high speed composite rotor, using expertise in high speed centrifuges developed at Capenhurst. Although the flywheel was successfully used in field trials in the traction application, and was used to demonstrate smoothing wind power fluctuations from a wind turbine in Japan, UPT ceased production in 2003.

Williams Hybrid Power developed flywheel technology for use in Formula 1 racing, and sold the technology to GKN where it is included in technologies for development of next-generation vehicles at the GKN UK Innovation Centre in Abingdon.

Innovate UK has funded several projects for development of flywheel application to vehicles. Developments for hybrid automotive drivetrain applications could have power grid applications that require high power, low energy storage.

More than a decade of research at Cambridge University has resulted in development of superconducting magnetic bearings for flywheels, suitable for application to the power grid and industrial uninterruptible power supplies (UPS).

OXTO Energy has developed a flywheel with a steel rotor to work alongside intermittent renewable generation.

Cryogenic energy storage

Highview Power Storage is a developer of utility-scale energy storage and power systems. Its proprietary process uses cryogenic (liquefied) air or its principal component, liquid nitrogen, as the working fluid and the medium for storing energy. Highview storage systems can be built with power from 10MW to over 200MW, and with storage capacity of 40MWh to over 2000MWh. A prototype 350 kW / 2.5 MWh Liquid Air Energy Storage pilot plant has been installed at the University of Birmingham Centre for Cryogenic Energy Storage.

A report Liquid Air on the Highway, presenting the environmental and business case for liquid air commercial vehicles in the UK, was published in 2014 by the Liquid Air Energy Network.

Pumped-heat energy storage (PHES)

Isentropic developed an energy storage system based on a reversible gas cycle which stores electricity in the form of thermal energy. The system is comprised of a hot and cold thermal store which are charged" and "discharged" by a reversible heat engine / pump.

A £15m investment by the Energy Technologies Institute (ETI) enabled a 150kW / 600kWh demonstration system to be constructed. The demonstration system was completed, commissioned and tested by a Newcastle University team. This pumped-heat technology potentially placed the UK as a leader in the R&D of low-cost and grid-scalable electrical and thermal energy storage.

Power to Gas

Power-to-gas includes electricity conversion, storage, and reconversion pathways that utilize gas for energy storage (hydrogen, ammonia, methane). This may be attractive where the stored energy has to be transported long distances before re-use, or where it may be flexibly integrated with other needs such as chemical feedstock or fuel for transportation or heating.

Siemens co-ordinated construction of an ammonia synthesis and energy storage demonstration system, at Rutherford Appleton Laboratory, and completed in 2018. The project was supported by Innovate UK and collaborators with Siemens included the University of Oxford, Cardiff University and the STFC.

Pumped Hydroelectric Energy Storage (PHS)

(Note that PHES is an alternative abbreviation that is sometimes used, however this may be confused with pumped-heat energy storage)
Pumped hydro storage accounts for the majority of all types of energy storage worldwide with total power 104GW in 2008, around 3% of generation capacity. Although in some geographical areas PHS may have limited potential for further deployment, many storage systems are under construction particularly in China, and a study published in 2018 identified pumped-hydro energy storage sites which have a global potential storage capacity of 22 million GWh.

Another possible application of gravitational energy storage is based on a simple principle: raising and lowering a heavy weight to store and regenerate energy. Like pumped hydro storage, the technology requires suitable geographic locations. Systems are being developed in the UK by Gravitricity and Escovale

Consultancy

Finally, there are several energy storage consultants in the UK, including EA Technology (who published a Good Practice Guide on Electrical Energy Storage and run the Energy Storage Operators Forum ESOF); Swanbarton Ltd (organiser of the International Flow Battery Forum); and Escovale Consultancy Services (publisher of a management report on Energy storage: Technologies, Applications and Markets).

Table 2.1 Capability Assessment

UK Capability	Area	Market potential
High	Battery energy storage. World-class expertise in materials science, lithium battery technology, including electrodes, liquid and solid-polymer electrolytes. Many UK Universities and high technology companies are currently active and collaborate in this field.	Global scope – high potential
High	Cryogenic energy storage	Global scope – high potential
High	Pumped heat energy storage	Global scope – high potential
High	Flow battery expertise and development capability. Several UK Universities and a UK company are currently active in flow battery technology development, including vanadium, zinc-cerium and lead-acid flow battery technologies.	Global scope – high potential
High	Flywheels with high-speed composite rotors, expertise and development. Several Universities conducted research in low-loss and superconducting magnetic bearings and cryogenics. Kinetic energy storage technology, developed by two UK companies and partners for the hybrid automotive drivetrain application, could be applied to electrical energy storage.	Global scope – high potential

3. Basic and strategic research

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UK Research and Innovation (UKRI) brings together the seven UK Research Councils (including EPSRC and STFC), Innovate UK, and Research England, and works in partnership with universities, research organisations, businesses, charities, and government to create the best possible environment for research and innovation to flourish.

This landscape section mainly includes EPSRC funding, while Innovate UK funding is included in Section 4 Applied Research, and STFC funding is included in Section 7 Networks.

The UK Government's Industrial Strategy Challenge Fund, delivered by UKRI, covers 15 Challenges of which two include energy and energy storage:

Faraday Battery Challenge (funding up to £246m)
Partly in response to the plan for all new vehicles to be electric and zero emissions vehicles by 2040, the Faraday Battery Challenge will invest in research and innovation projects and new facilities to scale-up and advance the production, use and recycling of batteries. This will also help advance development of batteries for other applications.

Prospering from the energy revolution (up to £102.5m)
The aim is to link energy supply, storage and use, and to develop systems to support the move to renewable energy, and funding will be provided to industry and researchers. Energy storage is included in the scope.

Grid-scale energy storage was identified as one of the Eight Great Technologies to drive UK growth in the UK Government's Autumn Statement 2012. In response to EPSRC's Capital for Great Technologies Call, grid-scale energy storage received an EPSRC Capital Grant of £30m, with capital funding provided to 17 Universities for 5 projects. (See Section 6).

The EPSRC Energy Programme supports several areas of energy storage research, as well as SUPERGEN, Doctoral Training Centres, and the UK Energy Research Centre.

Large EPSRC funded projects, described in Tables 3.1 and 3.2 include:
Energy Storage for Low Carbon Grids, (EP/K002252/1),
Integrated, Market-fit and Affordable Grid-scale Energy Storage (IMAGES), (EP/K002228/1),
Energy SuperStore SUPERGEN Hub (EP/L019469/1),
Energy Storage Research Network (EP/J021695/1).

EPSRC funding has provided a strong research base in Universities, that has led to projects such as FLEXIS (Flexible Integrated Energy Systems), a £24m research operation part-funded by the European Regional Development Fund and supported by the Welsh European Funding Office (WEFO). This project is developing an energy systems research capability, including storage within the Integrated Energy Supply Systems work package.

SUPERGEN is part of the EPSRC Energy Programme and is a key initiative in Sustainable Power Generation and Supply. It aims to contribute to the UK's environmental emissions targets through a radical improvement in the sustainability of the UK's power generation and supply. The first consortia were launched in 2003, and the SUPERGEN Phase 3 (2011-2017) supported seven Supergen hubs with £150m of investment over a five year period (including challenge calls and Centres for Doctoral Training). The following Supergen Phase 4 (2017+) featured an enhanced management structure and wider multidisciplinary involvement of Universities. The seven SUPERGEN

projects cover a wide spectrum of energy research and training and include the Supergen Energy Storage Consortium.

The 2013 Call for EPSRC Centres for Doctoral Training included energy storage within 14 priority areas. The EPSRC Centre for Doctoral Training in Energy Storage and its Applications started at the University of Sheffield and University of Southampton from 2014 onwards.

UKRI also provides funding for the UK Energy Research Centre (UKERC) and the Energy Technologies Institute (ETI); both include energy storage within their scope. After 12 years of research into low carbon technologies, the ETI is now closed. Available data and findings from the ETI's programmes are available online through the Programme pages and Knowledge Zone until 2025, and the project results will also be available from the ETI Publications component of the UKERC Energy Data Centre.

Table 3.1: Research Funding

Programme	Funding Agency	Description	Committed Funds	Period	Representative Annual Spend
Supergen (Sustainable Power Generation and Supply)	EPSRC	EPSRC project EP/L019469/1 SUPERGEN Energy Storage Hub. The SUPERGEN Energy Storage Hub (Energy SuperStore) includes 7 University partners (lead organisation University of Oxford, Imperial College, Universities of Bath, Birmingham, Cambridge, Southampton, and Warwick), and many industrial partners. The project is formed of nine Work Packages: one for each technology and three which address cross-cutting issues in energy storage research. The Work Packages are Redox Flow Batteries; Li-ion and Na-ion batteries; Lithium-air batteries; Supercapacitors; Thermal Energy Storage; Compressed Air Energy Storage; Whole System Modelling and Economic Analysis; System integration; Manufacturing and scale-up.	£3.91m	June 2014 to Dec 2019	£800k
EPSRC Research Funding for students	EPSRC	EPSRC issues block grants to particular universities via Doctoral Training Partnerships (DTPs), Centres for Doctoral Training (CDTs) or Industrial CASE (ICASE). The universities then manage the recruitment and selection of students to the projects that will be funded. Research grants awarded to institutions, including studentships for PhDs and Masters.			
EPSRC Centre for Doctoral Training in Energy Storage and its Applications	EPSRC	EP/L016818/1 EPSRC Centre for Doctoral Training in Energy Storage and its Applications, at the Universities of Sheffield and Southampton. The Centre of Doctoral Training trains researchers in all aspects of energy but concentrating on the core technologies of electrochemical storage (batteries and supercapacitors), mechanical storage, thermal storage and superconducting magnetic energy storage. Researchers	£4,078k	Apr 2014 to Sept 2022	£500k

		have the opportunity to interact with industrialists and gain experience in running a grid connected Lithium-ion battery. They will also undertake a major three-year research project allowing them to specialise in the topic of their choice.			
Energy Research Accelerator	Innovate UK	The Energy Research Accelerator (ERA) draws on the expertise and world-class facilities of many of the Midlands Innovation group of universities – Aston, Birmingham, Leicester, Loughborough, Nottingham and Warwick, plus the British Geological Survey. The group undertakes projects using a range of capabilities in energy generation, energy storage, energy integration, and energy use. Energy Storage projects include hydrogen, battery, thermo-mechanical, mechanical energy (Compressed air), thermo-chemical, and hybrid systems technologies The ERA is funded by Innovate UK, with match funding and support supplied by a range of industrial partners who are working together on a range of projects across the Midlands.	£60m	April 2016 onwards	
EPSRC Energy Storage Grand Challenge: Integrating Energy Storage for Future Energy Networks	EPSRC	The Integrated, Market-fit and Affordable Grid-scale Energy Storage (IMAGES) project (EPSRC EP/K002228/1). Lead organisation University of Warwick, with collaborators Loughborough University, the University of Nottingham and the British Geological Survey, focussed on the technical and economic issues when integrating large grid scale energy storage with the energy network.	£3.019m	Sep 2012 - Jun 2018	£500k
EPSRC Energy Storage Grand challenge: Integrating Energy Storage for Future Energy Networks	EPSRC	EPSRC project EP/K002252/1: Energy storage for Low-Carbon Grids. Consortium of 10 Universities, Imperial College (lead organisation), Cardiff University, Durham University, Newcastle University, University of Cambridge, University College London, University of Edinburgh,	£5.6m	Oct 2012 to June 2018	

		University of Oxford, University of Sheffield, University of Warwick; together with many industrial partners. The research aims are (i) developing novel approaches for evaluating a range of energy storage technologies; and (ii) innovation around four storage technologies; Na-ion, redox flow batteries (RFB), supercapacitors, and thermal energy storage (TES), relevant to grid-scale storage applications.			
EPRC Supergen Energy Storage Challenge	EPSRC	EP/N001877/1 Additive Manufacturing Next Generation Supergen Energy Storage Devices	£509k	Nov 2015 to May 2019	
ISCF Faraday Battery Challenge	UKRI	The ISCF Faraday Battery Challenge, is one of 15 Challenges funded by the Industrial Strategy Challenge Fund, and will develop batteries that are cost-effective, high-quality, durable, safe, low-weight and recyclable. Funding is provided for collaborative research and development projects, and includes creating the £78m Faraday Institution at the Harwell Science and Innovation campus to speed up research into battery technologies. Applied R&D projects led by Industry are described in Section 4 of this Landscape	up to £246m	2018-2022	£61m
Faraday Institution	UKRI	EP/S003053/1 unites the expertise and insight from its 7 founding partner universities (University of Oxford, UCL, University of Warwick, University of Cambridge, Imperial College, Newcastle University, University of Southampton), along with industry partners and other academic institutions, to accelerate fundamental research to develop battery technologies.	£55.7m	Jan 2018 to Jun 2021	£16m
ISCF Faraday Battery Challenge – fast start projects	UKRI	The Faraday Institution, opened in October 2017, awarded £42 million in January 2018 to four fast start research projects: • Battery Degradation • Recycling and Reuse (ReLiB) • Next Generation Solid-State Batteries (SOLBAT) • Multiscale Modelling	£42m	2018 onwards	

ISCF Faraday Battery Challenge: Faraday Institution - Battery Characterisation Call	UKRI	(Call for Full Proposals closed on 04 April 2019) The research topic is: To develop battery related characterisation; analytical techniques; and capabilities	£2m for up to 4 awards	July 2019 onwards	£1m
ISCF Faraday Battery Challenge: Faraday Institution - Round 2	UKRI	(Multiple Stage Call closed on 1 March 2019, Invitation for Full Proposals closed 30-May 2019, projects announced September 2019) The five research projects are: • Electrode manufacturing • Li-ion cathode materials (2 projects) • Na-ion batteries • Lithium-sulphur batteries	Up to £55m for five Consortia	September 2019 onwards	£12m
ISCF Prospering from the Energy Revolution	UKRI	Prospering from the Energy Revolution is one of 15 Challenges funded by the Industrial Strategy Challenge Fund and aims to create more efficient smart energy systems to intelligently link energy supply, storage and use and support the move to renewable energy.	up to £102.5m	2018-2022	£25m
Low Carbon Vehicle Technologies	EPSRC	EP/M009394/1 ELEVATE (ELEctrochemical Vehicle Advanced TEchnology). Lead organisation Loughborough University, with collaborators UCL, Warwick, Coventry, Oxford, Southampton and 9 industrial partners. The project will develop better materials for energy storage devices such as fuel cells and batteries and improve integration between devices, vehicles and power grids. The project has five interconnected work packages to identify, optimise and scale-up new materials into devices, develop novel diagnostic techniques in the lab and for on-board monitoring and control, and validate the technologies in a hybrid vehicle.	£3,266k	Jan 2015 - July 2019	£800k
Low Carbon Vehicle Technologies	EPSRC	EP/M009424/1 Ultra Efficient Engines and Fuels. Lead organisation University of Brighton, with collaborators Brunel University, University of Oxford, UCL, University of	£2,999k	Feb 2015 - July 2018	£1m

		Nottingham. The project considered methods for reducing fuel consumption of the internal combustion engine.			
UK-India virtual joint clean energy centre (JUICE)	EPSRC	EP/P003605/1 The Joint UK-India Clean Energy Centre (JUICE). Lead organisation Loughborough University, with collaborators and 10 industrial partners. The virtual centre brings together internationally leading experts in PV technology, applied PV systems, power electronics, electricity networks, energy storage and demand-side response; and will develop integrated solutions to ensure that the value of PV generation is optimised in both India and the UK.	£5,094k	Oct 2016 to Sept 2020	£1,250k

Table 3.2: Key Research Providers

Name	Description	Sub-topics Covered	No of staff	Field
University of Cambridge	Faraday Institution fast-start research project: **Battery Degradation** Led by the University of Cambridge with eight other university and 10 industry partners, this project is examining how environmental and internal battery stresses (such as high temperatures, charging and discharging rates) damage electric vehicle (EV) batteries over time. Results will include the optimisation of battery materials and cells to extend battery life (and hence EV range), reduce battery costs, and enhance battery safety. With Cambridge, university partners include University College London, Newcastle University, Imperial College London, University of Manchester, University of Sheffield, University of Southampton, University of Liverpool and University of Warwick.	• Battery materials • Battery life extension		ENGINEERING AND TECHNOLOGY
Imperial College London	Faraday Institution fast-start research project: **Multi-scale Modelling** Imperial College London is leading a consortium of seven other university and 17 industry partners to equip industry and academia with new software tools to understand and predict battery performance, by connecting	• Modelling and prediction of battery performance		ENGINEERING AND TECHNOLOGY

Name	Description	Sub-topics Covered	No of staff	Field
	understanding of battery materials at the atomic level all the way up to an assembled battery pack. The goal is to create accurate models for use by the automotive industry to extend lifetime and performance, especially at low temperatures. University collaborators include Imperial College, University of Southampton, University of Warwick, University of Oxford, Lancaster University, University of Bath, and University College London.			
University of Birmingham	Faraday Institution fast-start research project: **Recycling and Reuse** A project led by the University of Birmingham, including seven other academic institutions and 14 industrial partners, is determining the ways in which spent lithium batteries can be recycled. With the aim to recycle 100% of the battery, the project is looking how to reuse the batteries and their materials, to make better use of global resources, and ultimately increase the impact of batteries in improving air quality and decarbonisation. With Birmingham, university partners include the University of Leicester, Newcastle University, Cardiff University, University of Liverpool, Oxford Brookes University, University of Edinburgh, and the Science and Technology Facilities Council.	• Lithium battery recycling		ENGINEERING AND TECHNOLOGY
University of Oxford	Faraday Institution fast-start research project: **Solid-state Batteries** The University of Oxford is leading an effort with five other university partners and nine industrial partners to break down the barriers that are preventing the progression to market of solid-state batteries, that should be lighter and safer, meaning cost savings and less reliance on cooling systems. The ambition of this project is to understand the key chemical and fabrication challenges that would be inherent in the integration of batteries with a chemistry beyond Li-ion. With Oxford, university partners include the University of Liverpool, University of Cambridge, University College London, University of Sheffield and the University of St. Andrews.	• Solid-state batteries		ENGINEERING AND TECHNOLOGY
Aston University	School of Engineering and Applied Science EPSRC projects: • EP/S001778/1 Street2Grid - An Electricity Blockchain Platform for P2P Energy Trading	• power flows in the distribution network		Engineering and Technology

Name	Description	Sub-topics Covered	No of staff	Field
Cranfield University	Advanced Vehicle Engineering Centre • EP/L505286/1 Revolutionary Electric Vehicle Battery (REVB) - design and integration of novel state estimation/control algorithms & system optimisation techniques	• Electric vehicles • Battery		ENGINEERING AND TECHNOLOGY (Electrical and Electronic Engineering)
Heriot-Watt University	Heriot-Watt University Energy Academy is a centre of excellence and a gateway to Heriot-Watt's energy research and training activities. Research in the School of Engineering and Physical Sciences includes the theme electrochemical energy storage and conversion. Heriot-Watt is the sole academic partner in the ReFLEX (Responsive Flexibility) Orkney project, providing expertise in Whole System design and modelling (see Section 5.2). EPSRC project: • EP/S000933/1 Smart Microfluidics Towards Low-Cost High-Performance Li-Ion Batteries	• Li-ion Battery • Microfluidics • Whole system design and modelling		PHYSICAL SCIENCES AND MATHEMATICS (Chemistry) ENGINEERING AND TECHNOLOGY (Electrical and Electronic Engineering)
Imperial College London	• The Energy Futures Lab at Imperial College is a multidiscipline institute and focal point for a broad range of energy challenges in the five themes of Policy and Innovation, Energy Infrastructure, Sustainable Power, Low Carbon Cities and Transport and Clean Fossil Fuels. It operated the Energy Storage Research Network from 2012 to 2016. • Research Centres and Groups include: • The Control and Power Group in the Department of Electrical and Electronic Engineering • The Energy Group in the Department of Chemistry • Energy Storage Technologies within the Grantham Institute that includes research modelling how storage technologies could become part of a future energy system that integrates low-carbon power from intermittent, renewable sources.	• Integration of energy supply and storage • Nanostructured matrix material for structural energy storage • Grid-scale energy storage • Batteries and supercapacitors • Multifunctional structural carbon fibre composite supercapacitors • Energy storage		ENGINEERING AND TECHNOLOGY (Electrical and Electronic Engineering, Chemistry)

Name	Description	Sub-topics Covered	No of staff	Field
	• The Centre for Energy Policy and Technology (CEPT) • The Engineering and Physical Sciences Research Council (EPSRC) awarded £18.3m in 2013 to a consortium of 10 Universities, led by Imperial College, to develop new technologies for Energy storage for Low-Carbon Grids. • EPSRC projects: • EP/P007465/1 Beyond structural; multifunctional composites that store electrical energy £836k • EP/L014386/1 Business, Economics, Planning and Policy for Energy Storage in Low-Carbon Futures • EP/P033555/1 Towards a Parameter-Free Theory for Electrochemical Phenomena at the Nanoscale (NanoEC) • EP/K03619X/1 Reliable and Efficient System for Community Energy Solution- RESCUES • EP/L014343/1 Stability and Control of Power Networks with Energy Storage (STABLE-NET) • EP/N034570/1 RHYTHM: Resilient Hybrid Technology for High-Value Microgrids • EP/R030235/1 Resilient Electricity Networks for a productive Grid Architecture (RENGA) • EP/S025324/1 Discovering twisted bilayer materials with strong electron correlations • EP/N508585/1 Vanadium-Hydrogen flow battery for energy storage applications - a feasibility study • EP/L505298/1 Revolutionary Electric Vehicle Battery (REVB) • EP/L014289/1 Lower Cost and Longer Life Flow Batteries for Grid Scale Energy Storage • EP/R020973/1 ISCF Wave 1: Translational Energy Storage Diagnostics (TRENDs) • EP/N020707/1 Sincere: Selective ion-conductive ceramic electrolytes	network		

Name	Description	Sub-topics Covered	No of staff	Field
	• EP/P004504/1 Reduced Energy Recycling of Lead Acid Batteries (RELAB) • EP/P026478/1 Solid Oxide Interfaces for Faster Ion Transport (SOIFIT) • EP/R002010/1 Understanding the critical role of interfaces and surfaces in energy materials • EP/R004927/1 Prosperity Partnerships • EP/L024756/1 UK Energy Research Centre Phase 3 £13.5m			
Loughborough University	Research activities at the Centre for Alternative Energy Systems Technology (CREST) cover wind power, solar PV, energy in buildings, grid connection and integration, and energy storage (including hydrogen). • Loughborough University is the lead organisation in the EPSRC EP/M009394/1 ELEVATE (ELEctrochemical Vehicle Advanced Technology) project. (see Table 3.1). • Loughborough is the lead organisation in the EP/003605/1 The Joint UK-India Clean Energy Centre (JUICE) project (see Table 3.1). • Loughborough is a collaborator in the EPSRC EP/K002228/1 Integrated, Market-fit and Affordable Grid-scale Energy Storage (IMAGES) project, led by University of Warwick. (see Table 3.1)	• Grid integration • Thermal storage • Structuring of Li-ion battery materials • Diagnostics and metrology of battery operation • Vehicle to grid interface		ENGINEERING AND TECHNOLOGY (Mechanical, Aeronautical and Manufacturing Engineering; Electrical & Electronic Engineering; Chemistry)
Manchester Metropolitan University	The Manchester Fuel Cell Innovation Centre (MFCIC) is a £4.1m facility for fuel cell development, partly funded by the European Regional Development Fund. EPSRC Supergen Energy Storage Challenge project: • EP/N001877/1 Additive Manufacturing Next Generation Supergen Energy Storage Devices. • The project will develop unique 3D printed structures for supercapacitors and batteries which will give rise to significant improvements in energy storage characteristics.	• Fuel cell • 3D printing for fabrication of electrochemical platforms		ENGINEERING AND TECHNOLOGY (Chemistry; Chemical Engineering)
Newcastle University	The Sir Joseph Swan Centre for energy research includes the theme Grid systems and Energy Storage.	• Pumped thermal storage • Fuel cells		ENGINEERING AND TECHNOLOGY

Name	Description	Sub-topics Covered	No of staff	Field
	• EP/R021503/1 ISCF Wave 1: North East Centre for Energy Materials. • Newcastle University is the lead organisation in the North East Centre for Energy Materials (NECEM), together with the universities Durham and Northumbria, and 5 industrial partners.	• Electro-chemistry • Li-Ion, redox-flow batteries		
Queen Mary, University of London	The Division of Chemical Engineering and Renewable Energy is engaged in research in nanostructured functional materials and Metal Organic Framework (MOF) materials for energy conversion and storage. EPSRC projects: • EP/R021554/1 ISCF Wave 1:Designing Electrodes for Na Ion Batteries via Structure Electrochemical Performance Correlations. Queen Mary is the lead organisation, collaborating with University of Surrey, and 4 partners. • EP/N509899/1 Low-Cost Na-Ion Batteries	• Na-Ion battery • Battery electrodes		ENGINEERING AND TECHNOLOGY (Engineering and Material Science)
Queen's University Belfast	Research in the School of Chemistry and Chemical Engineering includes • EP/M021785/1 Design of a Novel Apparatus for the in-situ Formulation and Characterization of Safer Electrolytes • EP/L505262/1 Practical Lithium Air Batteries	• Battery Electrodes • Li-Air battery		ENGINEERING AND TECHNOLOGY (Chemistry)
Swansea University	The College of Engineering includes the Energy Safety Research Institute (ESRI) which is focussed on the security of supply, long-term sustainability and operational safety of energy systems. EPSRC project: • EP/N013727/1 A new concept for advanced large-scale energy storage: secondary batteries with seawater as open self-replenishing cathode. The aim is to explore a novel technology for large-scale energy storage. This involves the use of sea-water as a positive electrode (cathode) in a hybrid system which is intermediate between a secondary sodium-ion battery and a fuel cell.	• Sodium-ion battery • Fuel cell		ENGINEERING AND TECHNOLOGY (Chemistry)
University College London (UCL)	UCL Bartlett (Faculty of the Built environment) School of Environment, Energy & Resources • EP/N001893/1 Realising Energy Storage Technologies in Low-carbon Energy Systems (RESTLESS)	• Scenarios		ENVIRONMENTAL SCIENCES

Name	Description	Sub-topics Covered	No of staff	Field
University of Aberdeen	The School of Natural and Computing Sciences • EP/M029794/1 A first principles study of electric double layer capacitors	• Supercapacitors		ENGINEERING AND TECHNOLOGY (Chemistry)
University of Bath	Department of Chemistry • EP/K016288/1 Energy Materials: Computational Solutions • EP/N004302/1 Lattice-matched electrode-electrolyte interfaces for high-performance Li-batteries	• Materials • Li batteries		ENGINEERING AND TECHNOLOGY (Chemistry)
University of Birmingham	School of Chemical Engineering • EP/N032888/1 Multi-scale ANalysis for Facilities for Energy STorage (Manifest)	• Batteries • Grid ancillary service		ENGINEERING AND TECHNOLOGY (Electrical and Electronic Engineering)
University of Bristol	School of Physics EP/K016709/1 Fermi Surface Reconstruction in Cuprate High Temperature Superconductors	• Superconductor		Physical Sciences and Mathematics (Physics)
University of Cambridge	Energy Storage Research at University of Cambridge includes batteries and supercapacitors. EP/N001583/1 AMorphous Silicon Alloy Anodes for Multiple Battery Systems - "AMorpheuS" EP/P007767/1 Centre for Advanced Materials for Integrated Energy Systems (CAM-IES) EP/P003532/1 Next Generation Solid-State Batteries EP/P510142/1 Graphene coatings on Steel for large scale battery applications	• Battery materials • Batteries • Supercapacitors		ENGINEERING AND TECHNOLOGY (Chemistry, Engineering)
University of Durham	Durham Energy Institute has research projects in energy storage within smart energy systems, and energy materials. EP/P007546/1 Beyond structural; multifunctional composites that store electrical energy. The University of Durham is a collaborator in the North East Centre for	• Smart grids and energy storage • Polymers for energy storage		ENGINEERING AND TECHNOLOGY

Name	Description	Sub-topics Covered	No of staff	Field
	Energy Materials (NECEM), led by Newcastle University. EP/R021503/1 ISCF Wave 1: North East Centre for Energy Materials.			
University of Edinburgh	School of Engineering EP/P007805/1 Centre for Advanced Materials for Renewable Energy Generation EP/N508573/1 Two-Phase Polytropic Energy Storage	• Materials • Expansion and compression processes		ENGINEERING AND TECHNOLOGY (Engineering and Electronics)
University of Exeter	College of Engineering, Mathematics and Physical Sciences EP/P003494/1 Zinc-Nickel Redox Flow Battery for Energy Storage	• Redox flow		ENGINEERING AND TECHNOLOGY
University of Glasgow	School of Engineering EP/R020892/1 ISCF Wave 1: High Energy Density Capacitors Manufactured with Optoelectronic Tweezers (CapOET) EP/K022156/1 Scalable Solar Thermoelectrics and Photovaltaics. (SUNTRAP) EP/P00315X/1 (Iso)alloxazine incorporating electrodes as high-performance organic energy storage materials EP/N001982/1 Design and high throughput microwave synthesis of Li-ion battery materials EP/N001982/2 Design and high throughput microwave synthesis of Li-ion battery materials EP/K029290/1 Microwave processing for fast, green preparation of insertion electrodes	• Capacitors • Battery electrode materials • Li-ion battery materials		ENGINEERING AND TECHNOLOGY (Engineering, Chemistry)
University of Kent	School of Engineering and Digital Arts EP/R02331X/1 Formulating and Manufacturing Low Profile Integrated Batteries for Wireless Sensing Labels	• Integrated battery		ENGINEERING AND TECHNOLOGY (Engineering)
University of Leeds	School of Chemical and Process Engineering EP/N001745/1 Consortium for Modelling and Analysis of Decentralised Energy Storage (C-MADEnS)	• Energy system modelling and analysis		ENGINEERING AND TECHNOLOGY (Process, Environmental and Material

Name	Description	Sub-topics Covered	No of staff	Field
				Eng)
University of Liverpool	Department of Chemistry EP/R020744/1 ISCF Wave 1: Earth-Abundant Metal-Air Batteries EP/L505274/1 Practical Lithium Air Batteries EP/K006835/1 Role of Electrocatalysts in the Electrochemistry of Oxygen in Non-Aqueous Electrolytes EP/R000441/1 The Calcium-Air Battery	• Electrodes • Lithium-air battery • Calcium-air battery		ENGINEERING AND TECHNOLOGY (Chemical Engineering)
University of Manchester	School of Chemistry EP/K016954/1 Electrochemical Energy Storage with Graphene-Enabled Materials EP/M507714/1 Graphene enabled next generation battery technology EP/R023034/1 ISCF Wave 1: 3D electrodes from 2D materials EP/S004335/1 Understanding N-doped graphene electrocatalysts through in-situ characterisation EP/N001974/1 MY-STORE: Multi-energY storage-Social, TechnO-economic, Regulatory and Environmental assessment under uncertainty EP/L014351/1 Role of energy storage in enhancing operation and stability performance of sustainable power systems (RESTORES)	• Graphene enabled battery • Energy system modelling		ENGINEERING AND TECHNOLOGY (Chemical Engineering, Electrical and Electronic Engineering)
University of Nottingham	School of Chemistry EP/S001611/1 Unlocking Na-ion systems through interphase design EP/P023320/1 Generation Integrated Energy Storage - A Paradigm Shift EP/K036297/1 Intelligent MicroGrids with Appropriate Storage for Energy (IMASE) EP/R001251/1 Serial Hybrid Kinetic Energy Storage Systems - SHyKESS Collaborator in the IMAGES project (see Table 3.1)	• Na-ion battery • Integrated energy storage • Kinetic energy storage		ENGINEERING AND TECHNOLOGY (Chemical Engineering, Mechanical Engineering)
University of Oxford	Department of Materials EP/R023581/1 ISCF Wave 1: Materials research hub for energy conversion, capture, and storage EP/R030111/1 Robust Extra Low Cost Nano-grids (RELCON) EP/S001239/1 Novel Manufacturing Approaches to Next Generation Batteries EP/P005411/1 Structured electrodes for improved energy storage	• Battery materials • Battery electrodes		ENGINEERING AND TECHNOLOGY (Materials)

Name	Description	Sub-topics Covered	No of staff	Field
University of Sheffield	Department of Automatic Control and Systems Engineering EP/S001107/1 Affordable and clean energy via resilient and autonomous micro-grids EP/L016818/1 EPSRC Centre for Doctoral Training in Energy Storage and its Applications EP/L505900/1 Grid integration of multiple energy-storage flywheels EP/P002935/1 Higher Power Density Lead Acid Batteries EP/N022289/1 TransEnergy - Road to Rail Energy Exchange (R2REE)	• Micro-grids • Kinetic energy storage • Lead-acid battery		ENGINEERING AND TECHNOLOGY (Chemical Engineering, Electrical and Electronic Engineering)
University of Southampton	Faculty of Engineering EP/L001004/1 Battery Characterisation and Management - the key to Smart Grids and the Integration of Electric Vehicles EP/M02041X/1 Enhancing the specific energy of lithium-oxygen batteries by using redox mediators EP/N024303/1 Fundamental developments of lithium-oxygen and lithium-sulphur batteries by using redox mediators EP/P019099/1 Microgrid Energy Storage using Lithum-Sulfur Batteries EP/R021295/1 ISCF Wave 1: Improved lifetime performance and safety of electrochemical energy stores through functionalization of passive materials and components	• Battery characterisation and management • Li-oxygen battery • Li-sulphur battery • Passivation of materials		ENGINEERING AND TECHNOLOGY (Chemical Engineering)
University of St Andrews	School of Chemistry EP/I022570/2 Crossing Boundaries in Energy Storage (Oxford) EP/R023522/1 Emergent Nanomaterials (Critical Mass Proposal) EP/M009521/1 Enabling next generation lithium batteries EP/R030472/1 Enhancing Performance in Polyanionic Cathode Materials EP/P007821/1 Multiscale tuning of interfaces and surfaces for energy applications EP/I029273/2 Platform Grant Renewal - Materials for Lithium Batteries EP/P510282/1 Protected Anodes for Lithium Sulphur Batteries (PALIS) EP/L019469/1 SUPERGEN Energy Storage Hub EP/N508639/1 Scaled Electricity Storage Using Lithium-Sulfur Batteries	• Nanomaterials • Lithium battery • Electrode materials • Lithium-sulphur battery		ENGINEERING AND TECHNOLOGY (Chemistry)
University of Strathclyde	Civil and Environmental Engineering EP/R041822/1 Bioinspired green manufacturing of next generation energy storage materials (Sheffield)	• Materials • Pumped hydro		ENGINEERING AND TECHNOLOGY

Name	Description	Sub-topics Covered	No of staff	Field
	EP/T004681/1 Distributed pumped hydro for transforming energy and water access			(Chemical Engineering, Civil Engineering)
University of Surrey	Department of Chemical and Process Engineering EP/M027066/1 Designing Nanoporous Carbons as Anode Materials for Sodium Ion Batteries EP/R022852/1 ISCF Wave 1: High Power Material Hybridised Battery (HiPoBat) EP/K035002/1 Advanced fibre-based energy storage for wearable applications EP/K031562/1 Carbon Nanotube Based Textiles for Energy Storage Applications	• Electrode materials • Wearable energy storage		ENGINEERING AND TECHNOLOGY
University of Warwick	School of Engineering EP/S001905/1 Data-driven Intelligent Energy Management System for a Micro Grid EP/P012620/1 Surrogate Assisted Approaches for Fuel Cell and Battery Models EP/P026818/1 Energy Storage Electrode Manufacturing (ELEMENT) EP/N509863/1 Low cost storage of renewable energy EP/P510397/1 PALIS - Protected Anodes for Lithium Sulphur Batteries Warwick is the lead investigator in the Integrated, Market-fit and Affordable Grid-scale Energy Storage (IMAGES) project EP/K002228/1, (see Table 3.1)	• Energy management • Battery modelling • Na-ion battery • Li-sulphur battery		ENGINEERING AND TECHNOLOGY

4. Applied research

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Applied Research is funded by the UK Government primarily via Innovate UK, within the UK Research & Innovation (UKRI). Innovate UK was formerly known as the Technology Strategy Board (TSB) prior to 2014. Its role is to promote and support research, development and exploitation of technology and innovation for the benefit of UK business, in order to increase economic growth and improve the quality of life.

The UK Government's Industrial Strategy Challenge Fund, delivered by Innovate UK and UKRI, covers 15 Challenges which include energy and energy storage:

Faraday Battery Challenge (funding up to £246m)
Partly in response to the plan for all new vehicles to be electric and zero emissions vehicles by 2040, the Faraday Battery Challenge will invest in research and innovation projects and new facilities to scale-up and advance the production, use and recycling of batteries. This will also help advance development for other applications.

Prospering from the energy revolution (up to £102.5m)
The aim is to link energy supply, storage and use, and funding will be in industry and research to develop systems to support the move to renewable energy.

Table 4.1: Research Funding

Programme	Funding Agency	Description	Committed Funds (as of Sept 2019)	Period	Representative Annual Spend
Energy Research Accelerator	Innovate UK	The Energy Research Accelerator (ERA) is made up of eight internationally-renowned Midlands universities, part of the Midlands Innovation partnership, together with the British Geological Survey, and a large number of private sector collaborators. It is a high profile programme consisting of £60m capital investment from Innovate UK and £120m of match funding, from a large number of stakeholders. Partner universities are Aston, Birmingham, Cranfield, Keele, Leicester, Loughborough, Nottingham, and Warwick (Warwick Manufacturing Group). The ERA is addressing challenges in energy generation, energy storage, energy integration, and end use technologies. Key priorities within the ERA Energy Storage challenge are hydrogen storage (Birmingham, Nottingham), battery storage (Warwick, Leicester), thermo-mechanical storage (Birmingham, Loughborough, Nottingham and Warwick, and the British Geological Survey), mechanical energy (compressed air) storage (Nottingham), thermo-chemical storage, and hybrid systems (Birmingham). Members of the ERA are working with the Faraday Institution to help develop battery technologies, with topics including recycling and reuse, extending battery life and battery system modelling.	£60m	April 2016 onwards	
ISCF Faraday Battery Challenge	UKRI	The ISCF Faraday Battery Challenge, is one of 15 Challenges funded by the Industrial Strategy Challenge Fund, and will develop batteries that are cost-effective, high-quality, durable, safe, low-weight and recyclable. Funding is provided for collaborative research and	up to £246m	2018-2022	£61m

		development projects, and includes creating the £78m Faraday Institution at the Harwell Science and Innovation campus to speed up research into battery technologies. Research projects led by Universities are described in Section 3.			
ISCF Faraday Battery Challenge	UKRI	Funding for development of technology for electric car batteries was announced on 11 June 2019, to support innovative work of UK companies. Three awards were made to industry for development of a UK supply of lithium, maximising battery performance, and using artificial intelligence in battery manufacture.	£23m	June 2019	£5m
ISCF Prospering from the Energy Revolution	UKRI	Prospering from the Energy Revolution is one of 15 Challenges funded by the Industrial Strategy Challenge Fund and aims to create more efficient smart energy systems to intelligently link energy supply, storage and use and support the move to renewable energy. A Call for Detailed designs of smart, local energy systems(Close date 7 August 2019) invited proposals for designs for local energy systems, to deliver cleaner, cheaper energy services across a variety of technologies, markets, technological maturities and research categories. To bring forward novel research in local energy systems and accelerate uptake, value and impact, £8 million will go to setting up EnergyREV, an energy revolution research consortium.	up to £102.5m	2018-2022	£25m
Energy Systems Catapult	Innovate UK UKRI	Innovate UK established Catapult Centres as a new addition to its range of programmes to stimulate innovation. In addition to funding received from Innovate UK, direct contracts with UK business, as well	£270.9m (total for the High Value Manufacturing Centre and the	2018 onwards	£20m

		as external funding form a significant part of the overall funding for the Catapults. The Energy Systems Catapult has developed a range of unique Capabilities and Assets to help innovators, SMEs, industry, academia, regulators and Government to transform the UK energy system to meet carbon reduction targets and achieve our clean growth ambitions, and includes capabilities in Networks and Energy Storage.	Energy Systems Catapult)		
Energy Revolution Research Consortium (EnergyREV)	EPSRC UKRI	EP/S031863/1 Energy Revolution Research Consortium - Core – EnergyREV EP/S031898/1 Energy Revolution Research Consortium - Plus - EnergyREV - Next Wave of Local Energy Systems in a Whole Systems Context. The University of Strathclyde is leading EnergyREV, the Energy Revolution Research Consortium (ERRC) with 29 investigators across 22 universities, forming a network of researchers and stakeholders to help to put the UK at the forefront of knowledge services for integrated energy systems. The EnergyREV consortium will work with the Energy Systems Catapult to enable and inform demonstrators (funded by the ISCF Prospering from the Energy Revolution PFER programme) through their lifetime; undertaking analysis, evaluation and assessment of the demonstrators, building and driving best practice and leading knowledge exchange through national and international engagement with policy, academic and industrial communities. Additionally, EnergyREV will deliver its own strategic research projects that address some of the industrial challenges in developing local, investable, consumer-centred energy approaches. EnergyREV has shaped and defined a strategic programme of applied interdisciplinary research which	£7,966,339	Dec 18 - Mar 22	£2m

		aims to achieve significant outputs in the areas of whole energy systems and smart local energy systems. EnergyREV includes investigators in many Universities and has 20 industrial collaborators.			
Grid-scale energy storage R&D	EPSRC UKRI	Grid-scale energy storage was identified in the Autumn Statement 2012 as one of the Eight Great Technologies to drive UK growth. Grid-scale energy storage received an Capital Grant of £30 million with additional funding contributions of £9.8m from higher education institutions and £5.8m from industrial partners (total of £45.6m). Funding was provided to 17 Universities for 5 projects. (also see Section 6). • EP/K002252/1 Energy Storage for Low Carbon Grids • Grid Connected Energy Storage Research Demonstrator • Manchester-Liverpool Advanced Grid-scale Energy Storage R&D facilities • EP/L017725/1 Centre for Cryogenic Energy Storage • ThermExS Lab: thermal energy storage lab The IMAGES project was announced around the same time. EP/K002228/1 Integrated, Market-fit and Affordable Grid-scale Energy Storage (IMAGES)	£45.6m	2013 on	
Energy Technologies Institute - Energy Storage and Distribution	Energy Technologies Institute	The Energy Technologies Institute (ETI) was a public-private partnership between global energy and engineering companies and the UK Government. Its role was to act as a conduit between academia, industry and the government to accelerate the development of low carbon technologies. Energy storage and distribution was one of ETI's eight technology programme areas. An ETI project resulted in development of the world's first pumped heat energy storage system.			

		After 12 years of research, the Energy Technologies Institute (ETI) has now closed. Available data and findings from the ETI's programmes are available online through the Programme pages and Knowledge Zone until 2025, and the project results will also be available from the ETI Publications component of the UKERC Energy Data Centre. Much of the capability developed by the ETI now resides with the Energy Systems Catapult, the Centre for Sustainable Roadfreight and others. The Energy System Modelling Environment (ESME) developed by ETI was transferred to the Energy Systems Catapult.			
Carbon Trust Future Energy Systems	Carbon Trust	Established in 2001, the Carbon Trust works with businesses, governments and institutions around the world, helping them contribute to and benefit from a more sustainable future through carbon reduction, resource efficient strategies, and commercialising low carbon businesses, systems and technologies. The Carbon Trust co-ordinated funding by three major utilities, E.ON, SSE and Scottish Power, as well as the UK Department of Energy and Climate Change (DECC) and the Scottish Government to produce and publish an Energy Storage Report in March 2016			
Challenge Led Applied Systems Programme (CLASP)	Science & Technology Facilities Council (STFC)	STFC External Innovations runs a Challenge Led Applied Systems Programme (CLASP) to support the application and commercialisation of STFC research in the key global research challenge areas of energy, environment, healthcare and security. Individual annual calls are aligned to specific challenge areas. Key priority areas in the 2013 CLASP Energy Call included grid-scale storage methods. The scope of the CLASP 2021 Call is Healthcare and Energy.	£2m per annum, total for all challenge areas	2021	£600k total for all challenge areas

Table 4.2: Key Research Providers

Name	Description	Sub-topics Covered	No of Staff	Sector
ITM Power	ITM Power participated in a collaborative project together with E.ON, University of Nottingham and others, on coated metal hydrides for hydrogen energy storage. The project is part-funded by the Technology Strategy Board over the period 2011-2014. Hydrogen storage in metal hydrides could be part of an electrical energy storage system based on electrolysers and fuel cells. The Carbon Trust's Polymer Fuel Cell Challenge supported development of polymer fuel cells by ITM Power and ACAL Energy. ITM Power products are applicable to a range of energy storage markets including grid balancing, and storing renewable energy.	• Metal-hydrides for hydrogen storage • Fuel cell membranes • Hydrogen electrolysers		R&D Science and Engineering
Gravitricity	The Gravitricity energy storage project is developing a mechanical technology using gravitational potential for grid-connected energy storage.	• Gravitational energy storage		
Johnson Matthey Battery Systems	Johnson Matthey Battery Systems (Axeon was acquired by Johnson Matthey in 2012) is Europe's largest independent designer and manufacturer of lithium-ion battery systems, for electric and hybrid vehicles, as well as high volumes of batteries for e-bikes, power tools and mobile technologies. An EU-funded project SmartBatt (Jan 2011 - March 2013) aimed to develop the next generation of electric vehicle propulsion batteries which are both lighter and safer than their predecessors, and relied on technology and input from Axeon.	• Lithium-ion battery solutions for a range of applications • State-of-the-art battery management systems		R&D Science and Engineering

Name	Description	Sub-topics Covered	No of Staff	Sector
Nexeon	Nexeon was founded in 2005 and has patented a unique way of structuring silicon so that it delivers extended cycle life and significantly increases battery capacity. Nexeon's silicon anode materials enable lithium-ion batteries with greater energy storage capacity and/or smaller battery size, or for greater battery life between charges. Nexeon has offices in Japan and in the UK where it has a state-of-the art process development and manufacturing facility.	• Patented silicon anode materials for lithium-ion batteries • Increased energy capacity and battery lifetime		R&D Science and Engineering
OXIS Energy	OXIS is developing Lithium Sulfur [Li-S] battery chemistry that has the potential to revolutionize the rechargeable battery market. Li-S has a theoretical energy density 5 times greater than Li-ion.	• sulphur based cathode materials • highly stable electrolyte systems • anode made of Lithium metal and intercalation materials		R&D Science and Engineering
Invinity Energy Systems	UK-based redT and Avalon merged in 2020 as Invinity Energy Systems, a leading Vanadium Flow Battery company. redT has been developing its vanadium redox battery in the UK since 2001, partly supported by Innovate UK (formerly DTI & BIS) funding, and offers a modular product with capacity from 5kWh to 150kWh.	• Vanadium redox flow battery		R&D Science and Engineering
Ricardo - Energy and Environment	The TSB provided part-funding for the KinerStor project, announced in November 2009. Ricardo led a consortium including of industrial partners including CTG, JCB, Land Rover, SKF, Torotrak and Williams Hybrid Power, to demonstrate the viability of low-cost flywheel hybrid systems. The Kinerstor project forms part of the history	• Kinetic energy recovery systems in automotive hybrid drivetrain		R&D Science and Engineering

Name	Description	Sub-topics Covered	No of Staff	Sector
	of flywheel development in the UK.			
Siemens - Energy Storage Solutions	Siemens co-ordinated a Power-To-Gas and Energy Storage project, supported by Innovate UK. The project constructed an ammonia synthesis and energy storage demonstration system at the STFC site, which focussed on the use of ammonia as a carbon-free energy vector, and decoupling intermittent wind energy from the supply of firm energy to meet demand. Collaborators with Siemens included the University of Oxford, Cardiff University and the STFC.	• Storage of Wind energy • Synthesis of hydrogen and ammonia • Electricity regeneration from gas		R&D Science and Engineering
GKN Innovation Centre	GKN acquired Williams Hybrid Power Ltd (WHP) in 2014. Williams was a member of the KinerStor project consortium project, part-funded by the TSB, and developed an electro-mechanical composite flywheel system for use in Formula 1 racing. The hybrid flywheel technology was integrated in a car that won the 24-hr Le Mans for two consecutive years. The Kinerstor project forms part of the history of flywheel development in the UK. The technology provides a high-power solution for mobile or stationary energy recovery and storage, and is included in the development of next-generation vehicles at the GKN UK Innovation Centre in Abingdon.	• High power electromechanical composite flywheel system		R&D Science and Engineering

5. Development and Demonstration Funding

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In 2011 ABB commissioned its first DynaPeaQ energy storage installation for UK Power Networks at a site in Norfolk, England. The system is based on ABB's SVC Light technology, combined with Lithium-ion (Li-ion) battery storage. It is connected to an 11kV grid with considerable penetration of wind power, the first time an electrical energy storage device has been installed on an 11kV distribution network in the UK.

Ofgem funded demonstration projects via several funding mechanisms. The Energy Networks Association established the Smarter Networks Portal to share learning from projects.

The Energy Storage Operators Forum (ESOF) produced a summary of the electrical energy storage installation in the UK in 2013, State of Charge of GB, The summary lists projects by DNOs funded by Ofgem's Low Carbon Networks Fund (LCNF) and Innovative Funding Incentive (IFI). In 2013 there were 14 systems installed, under construction, planned or decommissioned, with a total power capability of 15.5MW and energy storage capacity 26.8MWh. The ESOF also produced a Good Practice Guide on Electrical Energy Storage.

The Renewable Energy Association (REA) produced a report, Energy Storage in the UK, An Overview, 2nd edition, that included details of energy storage projects in the UK as of Autumn 2016.

Demonstrations have shown that storage is commercially viable, providing a range of services ranging from balancing services such as firm frequency reserve, to trading using arbitrage, and facilitating the integration of renewable generation. The renewables trade association RenewableUK provides tracking information for members via its Project Intelligence Hub. Statistics on energy storage projects published by RenewableUK in December 2019 shows that energy storage power capability is increasing rapidly, with 0.742GW of operational battery storage capacity and over 10GW of planning applications. Pumped storage is also increasing from 2.833GW operational, and 1.796GW planned. While lithium batteries make up the majority of planned projects, the next phase of growth will include a range of new technologies. Companies ranging from Siemens to Highview Power are developing hydrogen, ammonia, and compressed air and liquid air storage technologies, with 0.600GW in development.

Table 5.1 Demonstration Funding Programmes

Programme	Funding Agency	Description	Number of projects	Committed Funds	Period	Representative Annual Spend
Ofgem Low Carbon Networks Fund (LCNF)	Ofgem	The LCNF ran from April 2010 until March 2015, with two tiers of funding. The 1st Tier of the LCN Fund allowed DNOs		Tier 1: £15m total Tier 2: Up to	2010 to 2015	

		to recover a proportion of expenditure incurred on small scale projects. Sep 2010 – Mar 2014 SSE 1MW Battery, Shetland £1m Oct 2011 – Mar 15 SSE Orkney Energy Storage Park and trial £1.81m The LCNF Tier 1 projects 2nd Tier of the LCN Fund provided DNOs with an annual opportunity to compete for funding for the development and demonstration of new technologies, operating and commercial arrangements. Up to £64m per annum was available through the LCN Fund. The LCNF Tier 2 projects		£64m per year		
Ofgem Electricity Network Innovation Competition	Ofgem	LCNF Tier 1 & 2, and IFI funding mechanisms were replaced by the Electricity Network Innovations Allowance (NIA) and Electricity Network Innovation Competition (NIC) funding mechanisms. The NIC is an annual opportunity for electricity network companies to compete for funding for the development and demonstration of new technologies, operating and commercial arrangements. The 2019 NIC funding decisions included an award of £21.2m across one gas and two electricity projects.		up to £70m per annum	2013 onwards	Up to £70m per annum
ETI Energy Storage and Distribution Programme	Energy Technologies Institute	The aim of the Energy Storage and Distribution Programme was to enable and develop the UK's energy infrastructure to manage fundamental long-term changes in • Energy generation source types and		£14m	2012 - 2017	£3m

		their geographic location • Energy demand patterns and energy usage requirements The original aim of an Energy Technologies Institute (ETI) Distribution Scale Energy Storage project was to develop and demonstrate a 1.5MW/6MWh energy storage device by Isentropic. See Table 5.2 for more details. After 12 years of research, the Energy Technologies Institute (ETI) has now closed. Available data and findings from the ETI's programmes are available online through the Programme pages and Knowledge Zone until 2025, and the project results will also be available from the ETI Publications component of the UKERC Energy Data Centre.				
DECC's Energy Storage Technology Demonstration	Department of Energy & Climate Change (DECC)	In 2012 the DECC had two energy storage innovation schemes: Feasibility studies into innovative and diverse energy storage ideas under the under the Energy Storage Technology Demonstration Competition (£0.5m for 12 organisations) Improvement of components or materials used for energy storage systems and feasibility studies to explore how storage systems can be used in the UK electricity network, under the Energy Storage Component Research & Feasibility Study Competition. (£1.5m for 4 companies)	4 Demo projects	£2m	2013-2015	£5m
Energy Innovation	Department	The Storage at Scale Competition (closed April	Up to 3	Up to £20m	2019	

Programme	for Business, Energy and Industrial Strategy (BEIS)	2019) objective is to demonstrate large-scale energy storage using innovative technologies, capable of operating cost-effectively with a target minimum output power of 30MW or minimum capacity of 50MWh for electrical energy storage technologies. The programme does not include conventional types of energy storage technology i.e. lithium-ion batteries, sodium sulphur batteries, lead acid batteries or pumped hydro.			onwards	
Faraday Institution	UKRI	The UK Battery Industrialisation Centre (UKBIC) (aka the National Battery Manufacturing Development Facility) is part of the Faraday Battery Challenge. It will enable the development of the next generation of battery systems including battery chemistry, electrodes, cell design, and battery modules, and cover all aspects of battery manufacturing. However most of the Faraday funding is for Strategic Research (Section 3) and for Applied R&D (Section 4). See the 2018 UK Governmenrt announcement about the Faraday Battery Challenge.		£80m	2017 onwards	
ISCF Prospering from the Energy Revolution	UKRI	Prospering from the Energy Revolution is one of 15 Challenges funded by the Industrial Strategy Challenge Fund and aims to create more efficient smart energy systems to intelligently link energy supply, storage and use and support the move to renewable energy. See the 2018 UK Government		up to £102.5m	£25m for 2018-2022	£5m

		announcement about the ISCF: ISCF Prospering from the energy revolution Four energy demonstrators were funded in April 2019, which include storage to some extent: • The Energy Superhub Oxford – project website • ReFlex - project website (REFLEX Orkney) • Project LEO - project website (Local Energy Oxfordshire) • SmartHubs SLES - project website				

Table 5.2: Major Demonstration Projects

Name	Description	Sub-topics covered	Total Project Cost	Public Sector Funder	Public Sector Funding	Period
DynaPeaQ Energy Storage (Norfolk)	A dynamic energy storage system deployed by UK Power Networks, and designed and built by ABB is the first time an electrical energy storage device has been installed on an 11kV distribution network in the UK. As well as providing dynamic voltage control, it will enable it will enable dynamic storage of surplus energy from wind farms, and can be utilized to level out peaks in grid loading and increase grid stability. Using this strategy, the power harnessed from the wind can be put to more efficient use than would otherwise be possible. Monitoring and analysis in being undertaken by Durham University.	• Deployed by UK Power Networks in an 11kV grid in Norfolk • Based on ABB's SVC Light® technology, combined with Lithium-ion (Li-ion) battery storage • Storage capacity 200kWh, power delivery 200kW for 1 hour or 600kW short-term • Reactive power control and dynamic voltage control • Provides active power control and grid stability improvement				2011
Shetland 1MW Battery	This Low Carbon Networks Fund (LCNF) Tier 1 project commenced in 2010 with the aim of installing a grid scale energy storage device in Shetland integrated with an active network management system. This was one of the first grid-scale battery systems in the UK. Three battery technologies were considered: Sodium Sulphur (NAS); Vanadium Redox; and Zinc Bromide. Although a	• NaS battery • Lead-acid battery • Peak lopping		Ofgem LCNF Tier 1	£1m	Sep 2010 to Mar 2014

	NaS battery (1MW 6MWh) was installed, this was removed in 2013 due to safety concerns, and a lead-acid battery system (1MW 3MWh) comprising 3166 cells was installed. The criteria for project success were to: • reduce the peak demand on Lerwick Power Station • for the battery to cycle efficiently to meet the needs and profiles of the islands' generation and demand • to increase the knowledge and understanding of battery operation within a network environment					
Orkney Storage Park Project	One of the first large-scale battery systems in the UK was the Orkney Storage Park Project Battery at Kirkwall Power Station. The lithium-ion 2MW 0.5MWh 0.25h battery system used two 12 m containers for its batteries and one for its power conditioning system, and was installed in 2013 by Mitsubishi Heavy Industries, Ltd. with Scottish Hydro Electric Power Distribution (SHEPD). Funding was provided by the Office of Gas and Electricity Markets (OFGEM) under its Tier 1 Low Carbon Network Fund (LCNF). The trial project ran until March 2015 and investigated how large scale batteries could absorb renewable energy to resolve intermittency issues.	• Renewable energy intermittency • Revenue streams including arbitrage		Ofgem LCNF Tier 1	£0.3m Trial £1.51m	Oct 2011 to Aug 2012 Trial until Mar 2015
Leighton Buzzard battery storage	The 6MW/10MWh facility in Leighton Buzzard commenced operations in 2014	• Smart network storage	£17.2m	Ofgem LCNF	£13.2m	2013 to 2016

facility	and was the UK's largest grid-scale battery storage facility at the time. It was funded by the Low Carbon Network Fund (LCNF), and helped to prove the technical and commercial viability of battery storage technologies. It is owned by UK Power Networks and was offered for sale in 2019 following Ofgem's decision that network operators cannot provide energy generation, including storage.					
ReFLEX (Responsive Flexibility) Orkney project	The project has been launched to digitally link distributed and intermittent renewable generation to flexible demand and storage. The project aims to create a 'smart energy island', demonstrating the energy system of the future, which will reduce and eventually eliminate the need for fossil fuels. Led by the European Marine Energy Centre (EMEC), the ReFLEX Orkney project brings together an expert consortium of Orkney-based partners – Solo Energy, Aquatera, Community Energy Scotland, Orkney Islands Council and Heriot-Watt University – as well as multi-national energy company Doosan Babcock.	• Batteries • Vehicle to grid (V2G) • Electric vehicles (EVs) • Hydrogen fuel cell • Distributed power system control • Whole System design and modelling	£28.5m	UKRI Industrial Strategy Challenge Fund	£14.25m	Apr 19 - Mar 22
Kilroot Advancion Energy Storage Array	The Energy Storage Array at Kilroot, Belfast, uses AES Corporation's advanced 10MW battery-based energy storage facility, and is the first transmission grid-scale array in the UK.	• Balancing • Integration of renewable energy sources	£2.4m	Innovate UK	£366,985	Apr 15 - Mar 18

	The array began operations on 5th January 2016. The project consortium demonstrating the capabilities of the storage array includes AES, Queen's University Belfast, System Operator for Northern Ireland (SONI), Northern Ireland Electricity (NIE) and the Utility Regulator. There are plans to increase the energy storage facility power to 100 MW. EPSRC Project EP/N508408/1 provided funding for Queen's University research.					
Pumped Heat Energy Storage (PHES) Demonstrator	Isentropic developed a Pumped Heat Electricity Storage (PHES) technology for large-scale energy storage. A £15m investment by the Energy Technologies Institute (ETI) enabled a 150kW / 600kWh demonstration system to be constructed. ETI continued the project with a Newcastle University Team (now at Durham University) who completed and commissioned the demonstration system, and collected the first performance data from a pumped heat energy storage system. The first tests indicated that with further testing and development, efficiencies in excess of 60% were viable. The pumped-heat technology potentially placed the UK as a leader in the R&D of low-cost and grid-scalable electrical and thermal energy storage.	• Pumped Heat Electricity storage • 150kW / 600kWh energy storage	£15.7m	ETI	£14m	2012 – 2019

6. Research Facilities and other Assets

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In January 2013, the UK Government announced funding for Eight great technologies including an extra £30 million to create dedicated R&D facilities to develop and test new grid scale storage technologies. In response to EPSRC's Capital for Great Technologies Call in July 2013, the EPSRC Capital Grant of £30 million for grid-scale energy storage included capital funding for 5 projects at 17 Universities:

- **Energy Storage for Low Carbon Grids** (£14.3m)
  Imperial College London, University of Birmingham, University of Cambridge, Cardiff University, Newcastle University, University of Oxford, University of Sheffield, University of St Andrews, University College London

- **Grid Connected Energy Storage Research Demonstrator** (£4.9m)
  University of Sheffield, Aston University, University of Southampton

- **Manchester-Liverpool Advanced Grid-scale Energy Storage R&D facilities** (£3.3m)
  The University of Manchester, University of Liverpool

- **Centre for Cryogenic Energy Storage** (£5.9m)
  University of Birmingham, University of Hull

- **ThermExS Lab: thermal energy storage lab** (£1.7m)
  Loughborough University, University of Nottingham, University of Warwick

The capital grants funded the building of energy storage pilot plants on university campuses at Birmingham, Manchester, Newcastle and Nottingham, together with the Sheffield facility at Willenhall on a public distribution network.

The EPSRC funded Manifest project (EP/N032888/1) builds on this investment, by conducting systematic comparative studies of the technologies. Dissemination is through an UK Energy Storage Observatory (UKESTO), a web-based portal with information on the facilities, and providing access to research outputs and data from operational runs of the pilot plants.

Table 6.1: Research Facilities

Name	Description	Type of asset	Scale of operation	Annual Operating Budget
Liquid-air	Liquid-air Energy Storage Pilot Plant at University of Birmingham	Pilot Plant		
Li-ion battery	Li-ion battery energy storage system at the University of Manchester	Pilot Plant 200 kW 240 kVA 100 kWh		
Battery and supercapacitor test bed	Energy storage test bed for batteries and supercapacitors at University of Newcastle	Pilot Plant		
Heat storage plant	Packed bed sensible heat storage at University of Nottingham	Pilot Plant		
Lithium Titanate (LTO) battery	Lithium Titanate (LTO) battery, part of a new 11kV Grid Connected 2MW Energy Storage Demonstrator based at the Willenhall primary substation, near Wolverhampton in the West Midlands, part of the Western Power Distribution's network. The battery is owned and operated by the energy storage research team at the Energy 2050 Research Institute at the University of Sheffield, in conjunction with partners at Aston University and the University of Southampton.	Pilot Plant		
National Centre for Energy Systems Integration (CESI)	The £20m EPSRC National Centre for Energy Systems Integration (CESI) is primarily funded by the Engineering and Physical Sciences Research Council	• Research Centre, aiming to optimise the energy network, including all aspects of supply and demand: • gas	£20m	

	(EPSRC) and Siemens. The balance of funding comes from industry and academic partners. The Centre draws upon the expertise of leading academics from the universities of Newcastle, Heriot-Watt, Sussex, Edinburgh, and Durham The Centre paves the way to a flexible smart infrastructure, empowering customers and giving them greater control of their energy use. It allows industry to meet the tough new low carbon targets.	• power • renewables • transport • heating • cooling		

7. Networks

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The Institution of Engineering and Technology (IET), Institution of Mechanical Engineering (IMechE), Institute of Physics (IOP), and the Energy Institute (EI), include storage in their energy agenda, and provide networking opportunities, information and events on energy storage.

The EPSRC-funded Energy Storage Research Network was set up in October 2012, bringing together researchers from academic, industrial and policy domains with an interest in energy storage and its application to future low carbon energy systems.

The UK Electricity Storage Network was formed in 2008 and is now managed by Regen, and complements the activities of the main trade association, the Electricity Storage Association which is mainly focussed on the USA but has an increasing international scope.

Other networks include the STFC Global Challenge Network in Batteries and Electrochemical Energy Devices (founded in 2013).
Conferences addressing mainly commercial and business aspects of electricity storage include the Energy Storage World Forum which is held annually in Europe and Asia. IQPC organised the Pan European Energy Storage Forum in London in 2010. A forum for flow battery developers, suppliers and users is provided by the International Flow Battery Forum, which holds annual conferences at international venues, including past conferences in the UK at Edinburgh in 2011, and in Ireland in Dublin in 2013.
EUROSOLAR, the European Association for Renewable Energy International, has organised a Renewable Energy Storage conference for eleven years.

Table 7.1 Networks

Network	Established	Description	Membership	Activities
Supergen Storage Network Plus 2019	July 2019	The aim of the ES-Network+ is to connect and serve the whole Energy Storage (ES) community including industry, academia and policymakers, and will complement existing activities (e.g. Faraday Institution, UKERC, Energy Systems Catapult, Centre for Research into Energy Demand Solutions (CREDS), and other Supergen Hubs). The Network will create, exchange and disseminate energy storage	• Researchers • Industry • Policymakers	The ES-Network+ project will develop an ES database and an authoritative ES whitepaper through ES network mapping, data gathering, and feasibility studies. The database and the whitepaper will benefit a large number of stakeholders. Academic and industrial stakeholders will develop pathways for future collaborative research

		knowledge and will support early career researchers. The project is led by University of Birmingham, and includes Supergen Storage investigators and 32 commercial organisations		programmes. Policymakers and public sector stakeholders will have access to ES experts for advice, thus shaping local and national energy policy in the longer term.
Energy Storage Research Network (ESRN)	Started in October 2012, and run by the Energy Futures Lab at Imperial College, the network was initially funded for a period of 3 years. The network has successfully to provide a focal point for news, events and opportunities for networking.	The Energy Storage Research Network brings together researchers from academic, industrial and policy domains with an interest in energy storage and its application to future low carbon energy systems.	• Researchers • Industry • Other stakeholders	Organising events, workshops and seminars on energy storage research and policy. Support and events with the aim of promoting UK energy storage research in both academia and industry.
Electricity Storage Network	The Electricity Storage Network was established in 2008 as an industry group dedicated to electricity storage. Regen took over management of The Electricity Storage Network in 2018.	The group is examining the issues for the greater deployment of electrical energy storage and provide a network for discussion of key issues. Mission: • To demonstrate the social, technical and economic benefits of electrical energy storage • To inform and educate • To present electrical energy storage as an integral part of the power network	• Policy makers • Developers • Researchers • Users • Other interested organisations	Activities include organising annual conferences organised jointly with the Institution of Mechanical Engineers. The network expects to cover the following activities over the next year: • Workshop meetings / seminars on key policy points • Further development of the strong interaction with policy makers • Dissemination of relevant news to members • Establishment and reinforcement of links with

				related organisations • Responses to other significant consultations
Electricity Storage Association (ESA)	Established by more than 30 utilities in 1991 as the Utility Battery Group (UBG). In May 1996, the scope was broadened to all energy storage technologies, and the name was changed to the Energy Storage Association. In April 2001, the name was changed to the Electricity Storage Association.	The Electricity Storage Association is an international trade association established to foster development and commercialization of energy storage technologies. The mission is to promote the development and commercialization of competitive and reliable energy storage delivery systems for use by electricity suppliers and their customers.	• Electricity utilities • Technology developers involved with advanced batteries, flywheels, CAES, pumped hydro, supercapacitors and component suppliers, such as power conversion systems • Researchers advancing the state of the art in energy storage solutions	ESA Goals: • Promote the commercial application of energy storage technologies as solutions to power and energy problems • Coordinate and attract international interest and involvement in energy storage. • Provide a forum for technical and commercial information exchange between suppliers, customers, and researchers.
Energy Storage Council	Established in USA	The ESC was founded to promote the research, development and deployment of storage technologies and to raise awareness of the importance of storage for the future of electricity supply and energy security in the USA. The mission is to ensure that the benefits of energy storage are fully realized by identifying, creating and executing programs that integrate energy storage into the national and state legislative agendas for energy production and delivery,	• Technology providers • Policy makers	• develops policies on key legislative and regulatory issues affecting the energy storage industry • acts as a central source of information and media contact • provides research and analysis of current market factors and developments in energy storage technologies • provides information about energy storage • maintains an online library of energy storage white

		environmental management, infrastructure, commerce, and national security.		papers
STFC Global Challenge Network in Batteries and Electrochemical Energy Devices	June 2013	The objectives of the network are to: Bring together an international community of researchers with an interest in battery and electrochemical energy device research. Encourage collaborations between researchers using large-scale facilities to promote standardisation of techniques and best-practice methodologies. The Network will fund activities to promote the use of large scale facilities to explore batteries and electrochemical devices- for example, by supporting researcher mobility through the STFC Futures Early Career Award Scheme.	• industry • academia • national laboratories • and all stakeholders with an interest in the application of large scale facilities	• networking events • best practice workshops • grants to ensure mobility of students and early-career researchers
IRES International Renewable Energy Storage Conference	August 1988 (Eurosolar)	EUROSOLAR, the European Association for Renewable Energy International, has organised a International Renewable Energy Storage Conference for eleven years. Electrochemical storage is one of the six technology sectors.	• Academia • Research institutes	• Conference and networking • publication of Open Access Conference Proceedings

8. UK Participation in EU Framework Programmes

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The table below lists the most relevant EU Framework projects with UK participation. The projects are presented in order of project start date (most recent first).

Horizon 2020 funded projects may be searched using a range of filters. Filters used here were Collection - Projects; Domain - Energy; Programme H2020; Start Date – from 1-Jan-2015; Total Cost – from €1m; Organisation Country – UK. This is clearly a subset of relevant projects, some earlier Framework 7 projects with UK participation are also included.

The EC supports many projects that advance batteries technologies to benefit consumers and industries, providing Reports and Initiatives on Batteries. Following the launch of the European Battery Alliance in October 2017, additional calls for proposals on batteries were published to further boost development. Projects funded within the Horizon 2020 programme from a cross-cutting call for proposals from 2019 are listed here.

Table 8.1: EU Framework Programme Participation

Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator and partners	Total Funding	EU Funding	Duration	Annual Spend
RECYCALYSE New sustainable and recyclable catalytic materials for proton exchange membrane electrolysers	Water electrolysis is a key technology for storing excess renewable energy. The EU-funded RECYCALYSE project aims to break the bottlenecks that hold back the further development of proton exchange membrane electrolysers, namely the high capital costs and the use of critical raw materials. The project will develop new catalyst supports and replace critical raw materials in catalysis with earth-abundant elements such as nickel, manganese and copper. It will then devise a recycling scheme for the new catalysts, electrodes and overall electrolyser system.	H2020-EU.2.1.3. H2020-EU.2.1.2. Industrial Leadership	RIA - Research and Innovation action	TWI Limited	Teknologisk Institut, Denmark (+10 partners)	€ 5.56m	€ 5.56m	1 April 2020 to 31 March 2023	€2m

Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator and partners	Total Funding	EU Funding	Duration	Annual Spend
	The sustainable development and management of materials could ultimately reduce EU imports and create a circular economy.								
LISA Lithium Sulphur for Safe Road Electrification	The Lithium Sulphur for Safe Road Electrification (LISA) 43 month project starts on the 1st January 2019. It is worth over €7.9m and consists of 13 European partners including OXIS Energy UK Ltd. The overall goal is to design and manufacture lithium sulfur technology that will enable safe electrification for EV applications.	HH2020-EU.2.1.3. H2020-EU.2.1.2. Industrial Leadership	RIA - Research and Innovation action	OXIS Energy, Cranfield University, Optimat Ltd	Acondicionamiento Tarrasense Associacion, Spain (+12 partners)	€7.9m	€7.9m	Jan 2019 to July 2022	€2m
E-MAGIC European Magnesium Interactive Battery Community	Energy storage is a key technology to facilitate a widespread integraWith the growing use of intermittent energy sources in power grids, there is a growing mismatch between when energy is produced and when it is consumed. This has led to the need of energy storage or demand-response systems in order to use the energy in a balanced and efficient way. Given this context, the Micro Energy Storage (MES) systems are expected to seek radically new approaches to supply energy where it is needed.	H2020-EU.1.2.2. FET Proactive	RIA - Research and Innovation action	University of Cambridge	Fundacion Cidetec, Spain (+9 partners)	€ 6.73m	€ 6.73m	1 Jan 2019 to 31 Dec 2022	€2.2m
ZapGoCharger	Zap&Go has developed a fast	H2020-	SME-2 -	ZapGo Ltd	ZapGo Ltd	€2.04m	€ 1.43m	Feb 2017 to	€700k

Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator and partners	Total Funding	EU Funding	Duration	Annual Spend
Rapid charging of cordless appliances using graphene-based supercapacitors	charging solution to appliances, devices and vehicles. In contrast to Lithium-ion batteries, Zap&Go's supercapacitors charge in 5 minutes or less and are safe to handle without fire risk. In this Phase II project Zap&Go will develop 1) supercapacitor power modules and electronics specifically integrating with cordless tools such as cordless vacuum cleaners and power drills and 2) build trial units to conduct customer trials.	EU.2.1.5. H2020-EU.2.1.3. H2020-EU.2.3.1. H2020-EU.2.1.2. INDUSTRIAL LEADERSHIP	SME instrument phase 2		(no partners)			Jan 2019	
NUOVOpb A unique Lead Acid Battery (LAB) recycling technology to reduce CO2 emissions by 89%, reduce waste by 81%, and transform the battery recycling industry	Aurelius Environmental Ltd has developed a novel hydrometallurgical process technology to recycle waste LABs in a highly energy efficient, non-polluting and cost effective way. NUOVOpb's commercial appeal lies in its low cost and scalability, and our ground-breaking ability to produce LAB-ready products that exceed the performance of current products on the market. Our LAB-ready paste can create new LABs with 22% greater energy capacity and 50% longer life. The technology has the potential to transform the global battery recycling industry, which has an	H2020-EU.3.5. Societal Challenges H2020-EU.2.3.1. Industrial Leadership	SME-2 - SME instrument phase 2	Aurelius Environmental Ltd	Aurelius Environmental Ltd (no partners)	€1.86m	€1.3m	1 Aug 2017 to 31 Jan 2019	€1m

Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator and partners	Total Funding	EU Funding	Duration	Annual Spend
	expected value of €9.5 billion in 2024.								
ALISE Advanced Lithium Sulphur battery for xEV	ALISE is a pan European collaboration focused on the development and commercial scale-up of new materials and on the understanding of the electrochemical processes involved in the lithium sulphur technology.	H2020-EU.2.1.3.2. Industrial Leadership. Materials development and transformation	RIA - Research and Innovation action	OXIS Energy Limited, Cranfield University, Williams Advanced Engineering Limited	Acondicionamiento Tarrasense Associacion, Spain (+14 partners)	€6.8m	€6.8m	1 June 2015 to 31 May 2019	€1.8m
ALION high specific energy aluminium-ion rechargeable decentralized electricity generation sources	The overall objective of the ALION project is to develop aluminium-ion battery technology for energy storage application in decentralised electricity generation sources.	H2020-EU.2.1.3.4. Industrial Leadership. Materials for a sustainable, resource-efficient and low-emission industry	RIA - Research and Innovation action	University of Southampton	Acondicionamiento Tarrasense Associacion, Spain (+11 partners)	€7.2m	€7.2m	1 June 2015 to 31 May 2019	€1.8m
BATTERY 2030+ At the heart of a connected green society	The BATTERY 2030+ initiative will be based on a multi-disciplinary and cross-sectorial approach to bring in all the necessary skills for developing future European battery roadmap while addressing a wide range of strategic applications. Three specific objectives have	H2020-EU.1.2.2. FET Proactive	CSA - Coordination and support action		Uppsala Universitet, Sweden + 16 partners	€499,456	€499,456	Mar 2019 to Feb 2020	€500k

Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator and partners	Total Funding	EU Funding	Duration	Annual Spend
	been defined: 1) BATTERY 2030+ roadmap establishment 2) Propose R&D actions and 3) Secure official stakeholder commitments.								
BATSTORM Battery-based energy storage roadmap	The BATSTORM project supported the European Commission and the European Technology and Innovation Platform (ETIP) for SmartGrids and Storage in their progress to identify and support RTD&D needs and market uptake of battery based energy storage. The project produced five reports, including: a) 10-year roadmap for 2018-2027 and short-term prioritisation b) Technical analysis of on-going projects Within the EU, six projects for stationary application were chosen for a detailed view, viz. ELSA; M5BAT; TILOS; InFluENCE; POWAIR; and SmartPowerFlow.	H2020	Supporting Action					2016-2018	
BRIDGE Cooperation group of Smart Grid, Energy Storage, Islands and Digitalisation H2020 projects	BRIDGE is a European Commission initiative that unites smart grid and energy storage projects funded under Horizon 2020. The group has published several reports. In 2018, the group	H2020	Supporting Action					2014-2019	

Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator and partners	Total Funding	EU Funding	Duration	Annual Spend
	published a Bridge battery report based on input from 15 projects involved in battery integration in the energy system, viz. CROSSBOW, EU-SYSFLEX, FLEXITRANSTORE, GRIDSOL, NETfficient, SMILE, TILOS, GOFLEX, INTEGRID, InterFlex, WiseGRID, ELSA, NOBEL GRID, STORY, and NAIADES. In June 2020 the group published a report and project fact sheets that includes details of 64 projects including links to project websites.								
ECLIPSE European Consortium for Lithium-Sulfur Power for Space Environments	This research action is aimed at developing Li-S technology for space applications, based on Lithium-Sulfur chemistry developed by OXIS Energy.	H2020-EU.2.1.6. INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies – Space		OXIS Energy Limited, Imperial College Of Science Technology And Medicine	Airbus Defence and Space SAS + 8 partners	€999,953	€999,953	Dec 2015 to Nov 2017	€500k
INFLUENCE Interfaces of Fluid Electrodes: New Conceptual Explorations	The INFLUENCE project aims to improve the fundamental understanding and control of interfaces of a battery type based on Li-ion and Na-ion active materials: semi solid flow batteries (SSFB).	FP7-ENERGY	Collaborative project (generic)	Imperial College of Science, Technology and Medicine	vito Vlaamse Instelling Voor Technologisch Onderzoek N.V. Belgium + 7 partners	€3.50m	€2.58m	Sept 2013 to Aug 2016	
HI-C Novel in situ and in	The primary goals are to:	FP7-ENERGY	Collaborative project	Uniscan Instruments	Danmarks Tekniske	€6.319	€4.646	Sept 2013 To	

Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator and partners	Total Funding	EU Funding	Duration	Annual Spend
operando techniques for characterization of interfaces in electrochemical storage systems	1) Understand the important interfaces in an operating battery on an atomic and molecular scale. 2) Characterize the formation and nature of interfaces in situ. 3) Devise methods to control and design interface formation, stability and properties. 4) Prepare ion-conducting membranes, mimetic of the polymeric part of the SEI, in order to study their mechanical and electrochemical properties.		(generic)	Limited	Universitet, Denmark + 7 Partners			Feb 2017	
SIRBATT (Stable Interfaces for Rechargeable Batteries)	SIRBATT is a collaborative project including 6 Universities, 1 Research Institute and 5 industrial partners. The organisations provide complementary expertise in experimental and theoretical studies of battery electrode interfaces. SIRBATT will develop microsensors to monitor internal temperature and pressure of lithium cells in order to maintain optimum operating conditions to allow long-life times that can be scaled for use in grid scale batteries.	FP7-ENERGY	Collaborative project (generic)	The University of Liverpool Johnson Matthey PLC	The University of Liverpool + 5 Universities, 1 research institute, and 5 industrial partners.	€4.4m	€3.14m	Sept 2013 to Aug 2016	€1m

9. International Initiatives

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The IEA Technology Collaboration Programme (TCP) supports the work of 38 independent, international groups of experts that enable governments and industries from around the world to lead programmes and projects on a wide range of energy technologies and related issues.

Table 9.1: International Activities

Name	Type	Description	UK Contact Point
IEA - Energy Conservation through Energy Storage (ECES)	IEA Technology Collaboration Programme	Energy Conservation and Energy Storage (ECES) facilitates integral research, development, implementation and integration of energy-storage technologies, and published a 2018 Annual Report. The main focus is thermal energy storage, while two Annexes are concerned with Electrical Energy Storage: Annex 28, Distributed Energy Storage for the Integration of Renewable Energies (completed) Annex 32, Modelling of Energy Storage for Simulation/ Optimization of Energy Systems (currently running) In June 2020 the IEA published a Tracking report, reporting that the size of the global market fell for the first time in a decade.	Dr Shane Long, BEIS
European Battery Alliance	European Cooperative Platform	This cooperative platform was launched by the European Commission in October 2017, and includes the European Commission, interested EU countries, the European Investment Bank, key industrial stakeholders, and innovators. The objective is to create a competitive manufacturing value chain in Europe with sustainable battery cells at its core, The Alliance brings together more than 250 industrial and innovation actors, from mining to recycling, with the common objective to build a strong and competitive European battery industry. Batteries Europe, launched in 2019, is the European technology and innovation platform of the European Battery Alliance.	via the European Battery Alliance website
EASE - European Association for Storage of Energy	European Cooperative Platform	EASE was established in 2011 and currently represents almost 40 members including utilities, technology suppliers, research institutes, distribution system operators, and transmission system operators. The mission is to: • Stimulate the development and deployment of innovative & cost-effective energy storage technologies • Promote a fair and future oriented energy market design that recognises storage	info@ease-storage.eu or via Regen, a Partner Organisation

		as an indispensable element of the energy system • Establish a platform for information-sharing on energy storage technologies and applications The EC - European Technology and Innovation Platform on Batteries was launched in February 2019 to provide support for research and innovation on all types of battery technologies, and consolidate the industrial basis for this sector.	